§10. Hard X-ray Image of ECH Plasma in LHD

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Hard X-ray images have been successfully obtained from electron cyclotron heating (ECH) plasmas in Large Helical Device (LHD). In the present article the hard X-ray image measured in LHD is reported with the time evolution of a hard X-ray spectrum.

The measurement of the hard x-ray image has been performed by using an assembly of a CsI implemented CCD camera. The quantum efficiency of a 1-mm-thick-CsI-photo luminescence plate attached in front of 512×512 semiconductor pixels of the CCD is good enough in the region between 20 keV and 60 keV. The assembly consists of a 2-mm-thick tungsten plate with a 2 mm diameter pinhole, a 3-mm-thick vacuum-tilt beryllium window, and an evacuating system. The CCD comprises a data acquisition system, a cooling system for semiconductor, and the CsI plate mounted inside a vacuum enclosure. Accordingly, X-ray emitted from LHD plasma is reduced by only the filters and the window. The assembly has been installed on a horizontal port of LHD and successfully operated with a computer.

The time evolution of the hard x-ray spectrum has been obtained with a conventional germanium-semiconductor detector as is shown in Fig.1. The plasma has been heated by only ECH. The bulk electron density is maintained to be 0.2×10^{13} cm^{-3}, since the hard x-rays are proved to be most intense.[1] As a result, hard X-ray is mainly emitted in the heating duration of 84 GHz. After the heating is finished at 750 msec, the emission gradually decreases in an exponential decay rate of 80 msec. In the decay phase the number of the high energy electrons is suggested to decrease much faster than the average energy of the electrons, since the decay rate of the intensity is independent on the energy of hard x-ray.

Figure 2 shows the hard X-ray image observed with the assembly of CCD. The accumulation time is approximately 20 sec, since fixed discharges have been repeated 20 times. The image magnification derived from the geometric relation of CCD, pinhole and plasma has been set to 100:3.4 in the case of the present experiment. Accordingly, the divergence of the sight line is corresponding to a spatial resolution of 20 mm at the plasma center. The image is reversed, since the assembly works as a pinhole camera. In the figure hard X-ray seldom seems to be emitted from plasma, while the most brilliant part is consistent with the positions of divertor plates in LHD. Consequently, the hard X-ray spectrum seems to be mainly contributed from the emission from the divertor.

The present experimental results suggest that the high energy electrons mostly emit hard X-ray at the divertor in the case of lower bulk electron density. After ECH heating the average energy of the high energy electrons is maintained, while the density of the high energy electrons exponentially decreases.

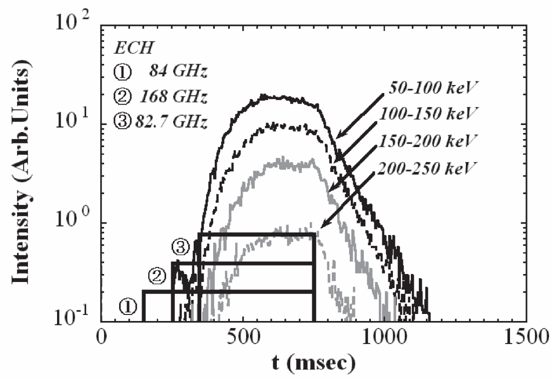

Fig.1. Time evolution of hard X-ray obtained from the conventional germanium-semiconductor detector. The heating duration of ECH is also indicated.

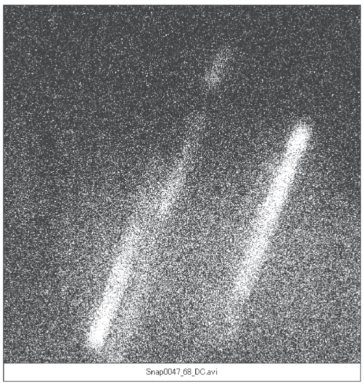

Fig.2. The hard X-ray image observed with the assembly of CCD. The frame size of the image is approximately 1 m. The horizontal axis is corresponding to the toloidal direction of the LHD plasma. The vertical axis is corresponding to the radial direction.

[1] Muto S., *et. al.*, Rev.Sci.Instrum. **74**(2003)1993.